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Anomalistics of physical and chemical parameters variability under anthropogenic and natural conditions in the four sectors of Aby lagoon (Ebrié lagoon system, Côte d'Ivoire)

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Abstract

This research aimed to determine anomalies in the physical and chemical parameters variability of the sub-lagoon Aby (Ebrié Lagoon, Ivory Coast). Data, generated from 2007-2009 at 18 study stations, were statistically partitioned using HAC, consolidated with the use of the k-means algorithm. That generated classification of the stations in two (02) groups. Group 1 is abnormally nitrogenous and has seasonal stratifications. This group consists of clusters 1 and 2 (stations 13, 10, 9 and 8; then 1, 12, 17 and 18 respectively) located in South-Aby and Ehy. Group 2 is more abnormal in nutrient than metal impacted. It is significantly influenced by nitrogen salts, phosphorus and mobilizable cadmium. This group is composed of clusters 3-7 which are mainly located in the lagoon entities Aby Nord and Tendo. In fact, beside the resuspension of the bituminous lagoon bottoms, the South-Aby and Ehy entities would have physical and chemical characteristics favourable to the human use of the Aby lagoon waters.

Keywords: Anomalies, physical and chemical parameters, heavy metal, nutrient, Hierarchical Ascendant Classification, Aby lagoon.

Introduction

The anomalies result from continuous deviations of varying heights in the variability of the parameters in systems. Resilience of the aquatic ecosystems can be negatively impacted if anomalies are not corrected in time. Thus, some heavy metals uptake by plankton instead of micronutrients occur within these environments[1]. In synoptic oceanography, understanding the effects of anomalies on the health of water bodies requires statistical analysis of physical and chemical parameters, among other things. Such activities are commonly carried out on surface water bodies in Côte d'Ivoire[2-5].

Most of large African cities of the south Sahara are built on the banks of river, lake, estuary or lagoon[6]. Therefore, various and multiform pressures are exerted on their physical and chemical balance, leading to ecological disasters most of the time. However, these water bodies support several socio-economic activities (tourism, harbours, fishing, etc.). Though they are frequently studied and sometimes even at the request of these countries, the fact outlines existence of patchy data. This observation biases decision-making regarding the management of temporal anomalies occurring in Ivorian lagoons.

The Aby Lagoon is a sub-unit of the Ébrié lagoon system (Côte d'Ivoire). Its watershed houses increasing mining, industrial and agricultural exploitations; in opposition with the building of mining and agricultural waste prior treatment infrastructures before their direct discharge into the Aby lagoon and through runoff. Thus, physical and chemical parameters in the Aby Lagoon were monitored from 2007 to 2009 with regards to these threats. The statistical analysis of these data revealed more or less pronounced variabilities. However, the preservation of this lagoon would be problematic without the profile of the anomalies in the variability of those physical and chemical parameters. This work is intended to be a tool to assist in the decision-making process for the use and protection of the Aby lagoon surface water. To do this, the data produced on the Aby lagoon[7] were partitioned into clusters using the Hierarchical Ascending Classification (HAC). A supervised learning computation allowed mapping of classes of the station according to the standards of the physical and chemical parameters of surface waters.

Research area: Aby lagoon is located South-east of Côte d'Ivoire and extends between 2°51'-3°21' E and 5°05'-5°22' N. That rural water body is the natural border between Côte d'Ivoire and Ghana, which holds more than a quarter of its area. This medium-sized estuarine lagoon extends 24.5km northwards and 56km from East to West. The semi-arid microclimate of the Aby lagoon is characterized by the intermittent coastal upwelling off the Ivorian coast. The climate is equatorial in

transition. It is marked by a dry and hot season (December-April) and a wet and cold season (May-November) combining rainfall and floods from the Bia and Tanoé rivers. These two rivers provide respectively $1.9,10^9 m^3$/year and $4.2,10^9 m^3$/year of continental water supply (92%). Diffuse runoff contributes $0.35,10^9 m^3$/year to this balance. Direct precipitation on the lagoon, which provides $0.9,10^9 m^3$/year, decreases in January-February and 64-69% of these inputs are evaporated[8]. The retention of Bia water by Ayamé 1 and 2 hydroelectric dams is combined with this phenomenon to promote seasonal stratification of surface water in the Aby lagoon during the dry season.

Methodology

Research data: Monthly data used in this research were generated from 2007-2009 during Akpétou's work. They have been averaged and constitute yearly observations of the physico-chemical parameters variability of the Aby lagoon waters. The 18 study stations were defined with regard to the continental and oceanic water inputs, and the anthropogenic pressures on the lagoon. Those pressures consist of waste discharges from mining and agricultural exploitations.

Collection of standards and threshold values for physical and chemical parameters of surface waters: A data frame of standards and safety threshold values mainly from the WHO manuals for physical and chemical parameters of the surface waters were compiled. That represented the reference by which the characterization of the physical and chemical anomalies was conducted. When these data were lacking, Ivorian standards and other scientific work were used (Table-1).

Table-1: Data frame of the standards and safety threshold values as reference for physical and chemical anomalies computation in our database generated from 2007-2009 in Aby lagoon.

Physical and chemical parameters	Units	WHO[8]	
		Guide level (it represents the ideal concentration)	Maximum admissible (it represents the start of the abnormal state)
pH	-	-	$6,5 \leq pH \leq 9,5$
Dissolved Oxygen	mg/l	5	10
Nitrites	mg/l	0,01	3
Nitrates	mg/l	-	50
Ammonia	mg/l	0,05	0,5
Lead (Pb)	mg/l	-	0,01
Cadmium (Cd)	µg/l	-	0,003
Manganese (Mn)	mg/l	-	0,4
Zinc (Zn)	mg/l	-	3
Temperature (T)	°C	-	$20 \leq T \leq 25,5$
Salinity (Sal)	-	0	3
Chlorophyl a (Chl_a)	mg/l	10	60
Transparence (Transp)	M	0,16	0,6
Depth	m	1	1,8
Kjeldahl nitrogen	mg/l	1	20
Total nitrogen	mg/l	0,05	0,5
Total Phosphorus	mg/l	0,05	0,2
Phosphate	mg/l	0,1	0,5
Suspended matters	mg/l	25	50
Cobalt	µg/L	-	0,5

Statistical analysis of research data: Data processing had required the use of the regularized iterative Principal Component Analysis (PCA) method[9]. Because there were some gaps in the data frame for the five (05) heavy metals studied. The regularized iterative PCA allowed to fill up these gaps while facilitating the reduction of the number and choice of dimensions for the interpretation of the observations. Details will not be given here. Anyway, it is important to note that the PCA standardizes the data and calculates the weight of each parameter in relation to a factorial plan. This should include as much information as possible from the original observation table. Therefore, data are suitable for classification[10].

We had computed the Hierarchical Ascendant Classification (HAC) that aggregates individuals (study stations here) with regard to their physical and chemical similarities. The finality is to characterize clusters of the studied stations in order to drawing awareness on their human utilization[11]. Finally, the anomalies by class of station were detected through a Datamining[12]. Specifically, that consisted of searching out and the detection of abnormal values in our database. And the stations were characterized with regard to relevant physical and chemical parameters.

Results and discussion

Hierarchical classification of stations in the Aby lagoon: Two groups of stations were generated with regard to their physical and chemical similarities. The Group 1 is abnormally nitrogenous and seasonally stratified while the group 2 is more abnormal in nutrient salts than strictly metal, impacted.

The group 1 consists of the clusters 1 and 2 (stations 8,9,10 in the South-Aby sub-sector and 13 in Tendo respectively). Depth, salinity and ammonium are the physical and chemical parameters or grouping factors. Group 1 is characterized by significant variability due to the effect of inland and ocean water transits in the Aby Lagoon[13]. Maintenance of shoals decrease salinity and ammonia (NH_4^+) in surface waters there. That is accentued by the short residence time of these waters in the lagoon. Cluster 2 (stations 1 in the North-Abysub-sector, 12 in Tendo, 17 and 18 in Ehy). The discharged organic matter into the lagoon, via runoff, enter into mineralization. Thus, concentrations of NTK, total nitrogen (N_tot) and transparency remained low during the study period.

Group 2 is formed by the clusters 3-7. In cluster 3, organic matter were highly mineralized (stations 14 and 16 of the Tendo sub-sector). That resulted of maximum concentrations of nitrites (NO_2^-), manganese and zinc that could be mobilized (Mn_Mob, Zn_Mob, nitrates (NO_3^-), then ammonia (NH_4^+). At clusters 4 and 5 (stations 7 and 6 respectively), total (P_Tot) and mineral (PO_4^{3-}) phosphorus and cadmium showed high concentrations. At clusters 6 and 7 of the stations 2 and 5; and then at the station 3, 4, 11 and 15 respectively; transparency, total suspended solids (MES_Tot), mobilizable cobalt (Co_Mob) and total nitrogen (N_tot) revealed high measurements.

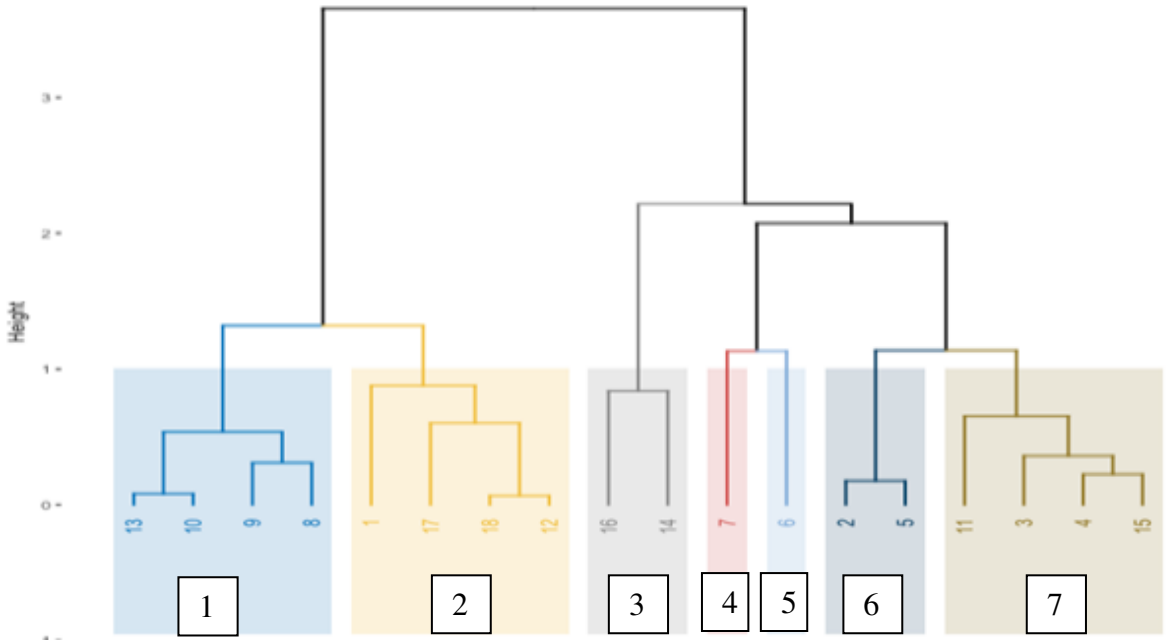

Figure-1: Dendrogram of the class of stations in the sub-lagoon Aby sectors. Clusters are chronologically listed from left to right. Boxes height displays the 'cutting' level (1) under the Kaiser criteria which recommend a choice of heigen values up to 1. Thus, boxes contain a maximum of information (x axis = inland and oceanic water inputs in Aby lagoon; y axis = wastes discharge in Aby lagoon).

Anomalistic characterization of the class of station in the Aby lagoon: For the purposes of our work, we have represented the abnormal state by 1 and 0 otherwise. Thus, the anomalistics of the cluster of stations are confined in the following tables:

Cluster-1: Salinity was measured in concentrations below 3, thus complying with WHO freshwater standards. This observation is underpinned by the importance of the depths (Depth) that stratify waters while promoting the predominance of ammonia (NH_4^+) as mentionned in Table-2.

Cluster-2: Organic nitrogen concentrations (NTK) and transparency (Transpa,) determined the anomalies in cluster 2. Thus, the total nitrogen (tot_N) is counterbalanced in NTK; making the tot_N a globally normal parameter for that cluster (Table-3).

Cluster-3: The mineralization of nitrogenous materials is favoured by the weakness of hydrology in cluster 3. They are mainly nitrated and acidified to ammonia. The shaping variables of cluster 3 are nitrites (NO_2^-), manganese and zinc that can easily be mobilized (Mn.Mob, Zn.Mob), nitrate (NO_3^-) and ammonia (NH_4^+). Thus, surface waters in cluster 3 were low in nitrites, unlikely nitrates and ammonia, which have shown unusual concentrations (Table-4).

Table-2: Physical and chemical characterization of the cluster 1 of the group 1 of the studied stations in Aby lagoon.

Group 1	Station	Sharping values and physical and chemical parameters			Coding of sharping values with regard to the standards		
		NTK	Transpa	Tot_N	NTK	Transpa	Tot_N
Cluster 1	1	0,24	0,58	0,47	1	0	0
	12	0,22	0,89	0,32	1	1	0
	17	0,24	0,66	0,68	1	1	1
	18	0,22	0,76	0,40	1	1	0

Table-3: Physical and chemical characterization of the cluster 2 of the group 1 of the studied stations in Aby lagoon.

Group 1	Station	Sharping values and physical and chemical parameters			Coding of sharping values with regard to the standards		
		NTK	Transpa	Tot_N	NTK	Transpa	Tot_N
Cluster 2	1	0,24	0,58	0,47	1	0	0
	12	0,22	0,89	0,32	1	1	0
	17	0,24	0,66	0,68	1	1	1
	18	0,22	0,76	0,40	1	1	0

Table-4: Physical and chemical characterization of the cluster 3 of the group 2 of the studied stations in Aby lagoon.

Group 2	Station	Sharping values and physical and chemical parameters					Coding of sharping values with regard to the standards				
		NO_2^-	Mn_Mob	Zn_Mob	NO_3	NH_4^+	NO_2^-	Mn_Mob	Zn_Mob	NO_3^-	NH_4^+
Cluster 3	14	0,67	138,29	205,98	1,85	32,38	0	0	0	1	1
	16	0,67	175,47	11,05	1,83	31,90	0	0	0	1	1

Cluster-4: Phosphorus (Tot_P, mineral-P) determined the formation of the cluster 4 which consists of station 7 only. Phosphorus compounds were abnormally measured in water in cluster 4. This could be a sign of intense phytoplankton activity (Table-5).

Table-5: Physical and chemical characterization of the cluster 4 of the group 2 of the studied stations in Aby lagoon.

Group 2	Station	Sharping values and physical and chemical parameters		Coding of sharping values with regard to the standards	
Cluster 4		Tot_P	$P0_4^{3-}$	Tot_P	$P0_4^{3-}$
	7	2,09	1,74	1	1

Cluster-5: The mobilizable cadmium (Cd_Mob) determined the formation of cluster 5. That cluster, formed by station 6 only, is characterized by abnormalities of cadmium concentration (Table-6).

Table-6: Physical and chemical characterization of the cluster 5 of the group 2 of the studied stations in Aby lagoon.

Group 2	Station	Sharping values and physical and chemical parameters	Coding of sharping values with regard to the standards
Cluster 5		Cd_Mob	Cd_Mob
	6	2,91	1

Cluster-6: Transparency (Transpa) is the only variable that ordered the formation of cluster 6. Transparency is almost superior to lagoon bottoms. Stations 2 and 5 were a similar physico-chemical ensemble, supported by the low Euclidean distance between them.

Table-7: Physical and chemical characterization of the cluster 6 of the group 2 of the studied stations in Aby lagoon.

Group 2	Station	Sharping values and physical and chemical parameters	Coding of sharping values with regard to the standards
Cluster 6		Transpa	Transpa
	2	1,41	1
	5	1,43	1

Cluster-7: The sharping variables of cluster 7 were total suspended solids (MES_tot) and total nitrogen (N_tot).The group of stations forming cluster 7 is, in its entirety, characterized by abnormally high concentrations of suspended matter (MES_tot) and total nitrogen. It should be noted that stations 4 and 15 have similar physico-chemical identities. They form an equally similar entity with station 3; which is in turn similar to station 11.

Table-8: Physical and chemical characterization of the cluster 7 of the group 2 of the studied stations in Aby lagoon.

Group 2	Station	Sharping values and physical and chemical parameters		Coding of sharping values with regard to the standards	
Cluster 7		MES_Tot	N_tot	MES_Tot	N_tot
	3	53,73	0,65	1	1
	4	56,60	0,90	1	1
	11	60,48	0,88	1	1
	15	5 : 3,83	1,02	1	1

Discussion: The revisitation of the data from Akpetou's work[7] made it possible to classify the study stations by similarity and physical and chemical homogeneity into seven (7) clusters. The variability of physico-chemical parameters at the stations had been highlighted by those authors. Our results are in line with their observations, which did not, however, identify the physical and chemical anomalies of the stations. Thus, cluster 7 (stations 3, 4, 11 and 15) is directly influenced by the terrigenic inputs from the Bia and Tanoé rivers[11]. Indeed, total suspended solids (TSS) showed high concentrations. These TSS include nitrogen, phosphorus and heavy metals salts. This has resulted in equally high turbidity. The synergistic effect of these salts and low transparency reduces the mineralization of the nitrogenous organic matters in these areas of the Aby lagoon by nitrating microorganisms[11]. Conversely, stations 2 and 5 of cluster 6 are outlying of the right of the Bia and protected from its pronounced hydrological effects. The waters are therefore clearer by mineralization and sedimentation of TSS, characterized by a transparency almost superior to the lagoon bottom. Under these conditions, this mineralization promotes the growth of plankton (especially Chl_a) and other bacteria that are potentially pathogenic to humans[5,14]. In fact, cadmium is highly mobilized at station 6, since it is also assimilated by plankton as a trace element[1]. This observation is supported by abnormally high phosphorus concentrations (mineral and organic); a limiting factor for primary production at station 7. Clusters 5 and 4 (stations 6 and 7 respectively) are likely to constitute an unfit area for human use of waters and fishery products[1,15]. Measurements of high concentrations of pathogenic microorganisms at these locations were run in the Aby Lagoon[5]. These two clusters (5 and 4) were characterized by a rich ecosystem in primary metal-dependent production[17]. Cluster 3 (stations 14 and 16) is shallow[11] (average depth = 2.6m). Its direct exposure to anthropogenic discharges from Tiapoum and neighbouring Ghana via the Tanoé River reduces the sedimentation of total suspended solids at these stations. Metals and nitrogenous materials are discharged to downstream stations. Zn and Mn, that can be mobilized, are in normal proportions, unlike nitrates and ammonium.

On the other hand, the relatively deep areas (clusters 1 and 2) experience the phenomenon of water stratification[11], the halocline being lower[13]. Nitrogenous materials sediment under the influence of ocean waters. They make the bituminous bottoms whose thickening affects the surface water layers in the event of disturbances of the water column by hydrology. Nitrogen remains mainly in organic form (NTK) which tends to acidify the environment (NH_4^+ anomalies) due to high insolation[16,18]. These abnormal concentrations of nitrogen compounds are the preferred substrate for the proliferation of microorganisms pathogenic to aquatic life and the subsequent food chain. In addition, these bituminous funds are periodically resuspended in the Aby lagoon[7]. This phenomenon wipes out the aquatic fauna and flora and is therefore the greatest threat for eventual fish farming projects in this lagoon.

Conclusion

The statistical analysis of the study data from Akpetou's[7], by Hierarchical Classification, generated a dendrogram with seven (07) clusters divided into two groups and consolidated with the K-means algorithm. The first group, nitrogenous with seasonal stratification, consists of clusters 1 and 2. These clusters are made up of stations 13, 10, 9 and 8 respectively; then 1, 12, 17 and 18. Cluster 1 in this group is characterized by anomalies in the ammonization of nitrogenous materials, which can support significant primary production. These areas would therefore be favourable to fish farming projects[13,15], subject to the control of episodic resuspension of the bituminous bottoms of the Aby lagoon[11]. On the other hand, cluster 2 (stations 1, 12, 17 and 18) is more exposed to organic matter decay due to the seasonal decrease in water transparency. The anomalies concerned the NTK and N_tot. The second group of clusters (3-7) is more dependent on nutrients than strictly metal impacted. These groups of stations are abnormal in phosphorus and nitrogen compounds (total and mineral), then in cadmium at station 6 of cluster 5, but clusters 4 and 5 (stations 6 and 7) were significantly abnormal in phosphorus compounds and mobilizable cadmium. The seemingly similar clusters 6 and 7, despite their high transparency, are loaded with total suspended matters containing potential metal toxics among others.

Group 2 of station clusters is abnormally nitrogenous and loaded with TSS, but transparent due to the ocean water inputs into the Aby Lagoon. The flushing effect of the Aby lagoon channel[13] increases these pollutant concentration there, exposing the North-Aby and South-Aby subsectors to caution in the human use of these areas. Group 1, which is more remotely located in the East, seems to be more suitable for human use of the Aby lagoon waters.

Finally, the monitoring of the water quality of this lagoon and many other water bodies will be facilitated by the data storage in a database. A data warehouse could be created for possible predictive analyses of spatial and temporal changes in physical and chemical or biological parameters of water bodies.

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